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(54) Title: METHOD FOR ON-SITE CASTING OF FREE-FORM CONCRETE STRUCTURES

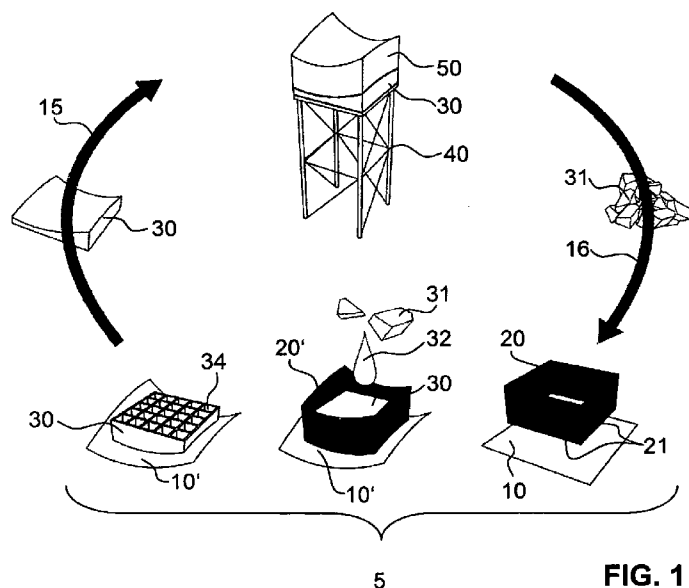


FIG. 1

(57) Abstract: A method for casting concrete or concrete like elements where said elements may have an amorphous shape, comprises the initial step of providing a mould, comprising a bottom surface (10') and side surfaces (20'), wherein the bottom surface (10') is an adjusted surface (10') having the curvature of the front surface of the concrete or concrete like element to be casted. Then molten wax (32) is poured into the mould. After solidification of the wax (32) a solid wax formwork element (30) has been formed, which can be mounted on a construction site into an outer load bearing support structure (40) creating a cavity of the concrete or concrete like element to be casted. After having poured fresh concrete or other concrete like material into the cavity, the concrete or other concrete like material is cured and the outer load bearing support structure (40) as well as the solid wax formwork element (30) are removed. Then the material of the solid wax formwork element (30) can be directly reused for providing molten wax (32) within the creation of a further solid wax formwork element (30).

TITLE

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Method for on-site casting of free-form concrete structures

TECHNICAL FIELD

10 The present invention relates to a method for on-site castings of free-form concrete structures according to the preamble of claim 1.

PRIOR ART

15

It is known for years from prior art to cast concrete according to a prefabricated scaffold on a site.

One example of a more sophisticated method to cast concrete is known from WO 2008/141
20 644. Said document discloses a method for casting and a formwork for casting concrete or concrete like elements where said elements may have an amorphous shape. This method allows a wide variety of shapes which could be symmetrical or asymmetrical. Said document starts with a solid formable material having a size larger than the element to be cast and a model of the element is then cut out creating the inner formwork. Said formable
25 material is especially an expanded polystyrene based product which allows a remanufacturing of said elements. An outer load bearing support structure is applied against the inner formwork. Then fresh concrete is poured into the space or cavity delimited by the inner formwork. It is also mentioned that optionally reinforcements can be arranged in the cavity. After a time period within which the concrete was allowed to cure,
30 the outer load bearing support structure and the inner form work parts are removed.

Within all milling methods, the work starts with a solid block, wherein these solids are square expanded polystyrene blocks or polymer blocks giving rise to the correct surface

form. However, after milling the surface needs to be covered with a coating in order to achieve an acceptable surface quality of the concrete. This method is time consuming and waste intensive and the expanded polystyrene (EPS) from the formwork elements is not reusable. Furthermore cutting the free-form structures out of a block of material is difficult
5 and costly and can only be used for small structures.

On the other side it is known to create free-form structures having a span of more than 10 to 15 meters through bending a wooden support structure as external formwork. This method is applicable for low-curvature geometries, having usually more than said 10 to 15
10 meter of curvature radius. Usually flat sheets of material are bent being engineered wood products such as OSB or ply wood onto a substructure of cleats, being pre-cut to the right profile curve of the surface to achieve. This method is as such limited to low curvatures and requires both digital fabrication methods and manual assembly. The material used to fabricate the non-repetitive form work elements is not-reusable.

15

A further approach was used in US 4,865,783, disclosing the fabrication of moulds for irregular prefabricated concrete elements using an organic polymer material with a melting point lower than 150 Grad Celsius. The negative form of the concrete is milled as disclosed in connection with WO 2008/141 644. Then the concrete is poured into the fixed mould.
20 After having extracted the concrete element and transported it away, e.g. on-site, the previously milled mould material is heated up, becomes liquid and together with additional organic polymer material it fills the mould for the milling step to prepare the basis for the next concrete element.

25 Flexible moulds are known from the article "Flexible Mould for Precast Concrete Elements" by Christian Raun, Mathias K. Kristensen and Poul H. Kirkegaard, in Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2010, Shanghai; 8-12 November 2010, Shanghai, China. The teaching of this document allows casting of thin-shell concrete elements.

30

SUMMARY OF THE INVENTION

It is therefore an object based on the prior art techniques to fabricate reusable non-repetitive formwork elements for on-site casting of free-form concrete structures. Such structures would be able to support the expanding markets of buildings using non-repetitive free-form geometry, in which concrete is used as the structural material which is cast on-site.

Further advantages of the present invention over existing prior art can be found in the area of environmental and economical sustainability.

The invention is based on the insight, that one particular challenge when casting free-form concrete elements is the load bearing support structure. WO 2008/141 644 shows that full solid material as expanded polystyrene is used as formwork basis. It is not possible to create forms as disclosed in WO 2008/141 644 with a thin plastic material backing in bigger dimensions. The same is true for US 4,865,783, disclosing a mould having five fixed sides and the concrete cannot be prepared on-site.

The method for casting concrete or concrete like elements where said elements may have an amorphous shape, comprises the initial step of providing a mould, comprising a bottom surface and side surfaces, wherein the bottom surface is an adjusted surface having the curvature of the front surface of the concrete or concrete like element to be casted. Then molten wax is poured into the mould. After solidification of the wax a solid wax formwork element has been formed, which can be mounted on a construction site into an outer load bearing support structure creating a space or cavity of the concrete or concrete like element to be casted. After having poured fresh concrete or other concrete like material into the cavity, the concrete or other concrete like material is cured and the outer load bearing support structure as well as the solid wax formwork element are removed. Then the material of the solid wax formwork element can be directly reused for providing molten wax within the creation of a further solid wax formwork element.

Further embodiments of the invention are laid down in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are described in the following with reference to the drawings, which are for the purpose of illustrating the present preferred embodiments
5 of the invention and not for the purpose of limiting the same. In the drawings,

- Fig. 1 shows a schematic sketch of the different method steps of a method according to an embodiment of the invention;
- Fig. 2A-2F show specific sub-steps of the method according to an embodiment of the
10 invention for fabricating an improved mould;
- Fig. 3 shows a schematic perspective view of the use of the moulds fabricated according to an embodiment of the invention;
- Fig. 4 shows a cross-section of Fig. 3; and
- Fig. 5 shows a more detailed partly transparent view of the mould according to an
15 embodiment of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

- 20 Fig. 1 shows a schematic sketch of the different method steps used within an embodiment according to the invention. It is especially noted, that the method according to the invention allows for a reuse of the material, wax 31, forming the inner structure or wax formwork element 30.
- 25 As will be explained in connection with Fig. 2A to 2F the fabrication of the inner structure starts within a specific fabrication site with an adjustable initially planar smooth surface 10 onto which a mould frame 20 can be positioned. The fabrication site has received the general reference numeral 5 covering all steps executed at that site, which can also be a site on an installation site. The mould frame 20 preferably has four sides spanning a
30 rectangular form; however other polygonal forms are possible, but not preferred. The lower edge 21 of the mould frame 20 is adapted to contact the initially planar surface 10 in a sealing manner.

Plan 10 is especially an adjustable material, e.g. a plastic sheet or a reinforced plastic sheet or a textile structure. Such a structure is known from the paper from Christian Raun et al. mentioned in the introduction of the specification.

- 5 Within the fabrication of the mould the adjustable initially planar surface 10 will be manipulated in its height in the two plan dimensions in order to follow the free-form structure for the negative workform of the concrete. Thus the form of the surface 10 represents the positive form as the concrete will show up after the casting. This is shown for the surface 10 having received the reference numeral 10' for the adjusted surface.
- 10 Preferably the mould frame or outer frame work 20 is flexible and follows the curvature of the adjusted surface 10' and has therefore received the numeral 20' for adjusted mould frame walls.

Then the wax formwork element 30 is formed through melting pieces of wax 31 and
15 pouring the wax in a molten state as molten wax 32 into the form provided on five sides by the adjusted elements 10' and 20'. Then the wax 31 solidifies and creates the wax formwork element 30. Preferably the molten wax 32 is poured near and at the lowest part of the adjusted mould part elements 10' and 20'. Additionally the adjustable mould frame parts 20 as well as the adjustable initially planar surface 10 can be equipped with heating
20 elements, e.g. electric heating cables at their back surface to heighten the temperature of the frame to a temperature in the vicinity of the fusion temperature of the wax 31 to allow a controlled solidification of the molten wax 32 in the form.

Preferably the wax formwork element 30 is not a full solid but comprises a number of
25 indentations 34 on its back as will be explained in connection with the description of Fig. 2A to 2F. The aim of providing these indentations 34 is to reduce the weight of the wax formwork element 30 without compromising its stability.

Then usually the adjusted mould frame 20' is taken away and the wax formwork element
30 30 is taken from the fabrication site 5 which is shown with the arrow 15 to be mounted on-site on or within a support structure 40, which is here shown as a scaffold. Then concrete is poured onto this structure being the wax formwork element 30, having walls within a side frame (not shown in Fig. 1), as will be explained in connection with Fig. 3 and 4 providing

the concrete structure 50.

After having cured the concrete structure 50, the wax 31 can be taken away and reused. The wax formwork element 30 can then be destroyed on-site and wax chunks can then be
5 reused according to arrow 16 for the transport from the installation site to the fabrication site 5 to model a new wax formwork element 30.

The fabrication site 5 can be provided at a complete different place than the installation site or it can be provided near the construction site.

10

Fig. 2A to Fig. 2F show different specific sub steps of the method according to an embodiment of the invention which is executed at the fabrication site 5. These sub steps explain and comprise features relating to the additional structural features of the indentations 34 in order to obtain a lighter weight wax formwork element 30.

15

Fig. 2A shows the adjustable initially flat surface 10, the supporting structure as a mould frame 20 as well as a blockarray 60 or counter mould, comprising a number of here $5 \times 5 = 25$ single arrayed blocks 61. The arrayed block 61 can have a square basic surface 62 and being of rectangular shape. Usually they are attached at their backside opposite to the
20 surface 10 to fixation elements and or there might be guide elements between the different arrayed blockcolumns 61. It is noted that the blocks 61 do not touch each other but are separated by a small arrayed block gap 63 providing a distance between the blocks 61. Preferably the arrayed block gap 63 is constant over the length of the blocks 61 or is slightly conical, wherein the lower square surface 62 near the adjustable initially planar
25 surface 10 is smaller than the upper square surface on the opposite free ends of the block 61. Said gap 63 is preferably the same between blocks 61 in different rows as well as in different columns of the array 60. These blocks could be moved by an actuator or by a robot bringing them into a specific predefined place.

30 In a further embodiment, not shown in the drawings, the arrayed blocks 61 are placed as and in an irregular grid. In other words, each arrayed block 61 may have a different lower surface 62 with different dimensions. The lower surface 62 may be rectangular, having polygonal edges or is a circular disc. Therefore the gaps 63 can be of different thickness

and also comprise a curvature if looked on from above. Such different sizes of the “foot” of the arrayed blocks 61 would be able to adjust to different curvatures and concrete pressure demands.

- 5 An arrayed block 61 is, in the simplest form, a vertical rod being adjustably attached to a frame structure and/or with adjacent arrayed blocks 61. Preferably the arrayed blocks 61 are cylinders in the geometrical sense, thus comprising prisms etc. .

The adjustable mould frame work 20 is positioned on the adjustable initially planar surface
10 10 and the adjustable surface 10 is formed according to a predefined free form curvature in two directions. The adjustable surface 10 does not follow necessarily or exclusively a double curve geometry. This can be achieved as shown in section 3.1 of the Raun et al. publication. After having formed the lower support structure 10 as well as the frame work 20 into the configuration 10' and 20' as shown in Fig. 2B the array 60 of elements 61 is
15 positioned, as shown in Fig. 2C, wherein specific height positions of the elements 61 are provided in order to generate specific dimensions of a space or cavity between the surface 10', the frame work 20' and the single columns 61 as it will be explained in connection with Fig. 5. It is also possible, that all or parts of the arrayed blocks 61 are heated as mentioned above.

20

Then molten wax 32 is poured into the existing cavity which gives the result as shown in Fig. 2D after having removed the adjusted frame work 20' when the wax 31 in liquid form has solidified. Then the array 60 of blocks 61 is removed which gives rise to the final result of the wax formwork element 30 with indentations 34 as positioned on the surface
25 10' shown in Fig. 2E.

The final stage is then taking away the wax formwork element 30 from the surface 10' and said wax formwork element 30 can then directly be used on site.

- 30 It is possible to use the wax formwork element 30 to case single sided for e.g. deck like structures.

Instead of forming the initially flat adjustable surface 10 into the surface 10' it is also

possible to provide initially a set of adjustable moulds 10' forming the required surface which can then be stored. These surfaces 10' can be provided as a thin-shelled mould, since the positive form is light weight wax 31. Therefore a simple under structure as explained in the paper of Christian Raun et al. can be used.

5

Then the wax 31 is cast on the adjusted mould 10' to form the wax formwork element 30. After having placed on-site the wax formwork element 30 the concrete 50 is casted. Removing and breaking away the wax form elements 30 allows reusing the basic material, the wax chunks 31 to prepare new wax formwork elements 30 for the next project phases.

10

It is especially advantageous to use this method for curvatures having a radius smaller than 15 meter since the person skilled in the art is thus technically unhindered by bending material properties and for elements having dimensions and radius larger than 1,5 meter for which milling becomes very expensive.

15

Using the wax 31 for the fabrication of non-repetitive free-form formwork elements 30 out of a reusable material is a formative fabrication method, rather than a subtractive fabrication method and results only in minor material loss. The wax formwork element 30 is reusable using only a reasonable amount of energy, since this relates to the energy
20 needed to melt and to pour molten wax 32 into a new form which is only a fraction of the embodied energy of the wax itself. This is a far more efficient process than milling expanded polystyrene blocks.

25

The wax 31 is a one-time investment within the process and thus the cost decreases with the increased number of uses of the same wax 31 within the process.

30

The wax 31 can be more or less any kind of wax or polymer material having a softening point not lower than 70 degrees centigrade (70° Celsius) and having a melting point not higher than 90 degrees centigrade. Although it is possible to use a material having a
30 melting point at a temperature higher than 100 degrees centigrade, such materials are not preferred since they require the use of more energy for converting the wax into its molten state. One important feature of the wax or polymer material in this respect of the possible higher melting point is the fact that the material does not show cracking effects during

shrinkage while solidifying and cooling down to ambient temperature. This is usually connected to the thermal expansion coefficient but is also a property of the material.

5 The wax 31 can be in general any thermoplastic material, defined as a material, especially a polymer, that becomes liquid, i.e. melts, when heated and can be remelted and remoulded, wherein the crackwidth after return to ambient temperature is below a predefined threshold not compromising structural integrity of the element. Usually such a predefined threshold could be 0,5 millimeter, preferably below 0,2 millimeter.

10 The softening point should not be below said 60 or 70 degrees centigrade since the curing of the concrete raises the temperature of the form up to 40 or 50 degrees centigrade. Furthermore the wax form element 30 might be subjected to sun exposure which also raises the temperature of the wax form. Therefore it is preferred that the softening point of the wax should be around 70 to 80 degrees centigrade.

15

A further advantage of the process is the possibility to use the wax form directly to pour concrete on it without using any release agent. The adjustable initially planar surface 10 is obtained through uniformly spaced individually actuated supports with a semi-rigid top surface. It is also possible to adjust the surface 10' without an adjustable semi-rigid
20 continuous top surface. It is possible to use closed pack continuous supports with an elastic interpolating top surface. They can be actuated internally or shaped externally. The adaptable edge solution is in fact a 2D-pin bed allowing to provide the adjusted mould frame walls 20. The number of arrayed supports below the adjustable planar surface can be e.g. $36/\text{meter}^2$.

25

A very simple solution is using a box providing the mould frame 20 as in US 4,865,783. On the underside of the box a continuous bed of pins with a number of e.g. $10'000/\text{meter}^2$ is provided. The advantage of the pin bed relates to the larger curvature range through the increased number of arrayed supports/pins. On the other side, preparation of the pin bed is
30 more expensive.

Fig. 3 shows a schematic perspective view of the use of two moulds 130 and 230 fabricated according to an embodiment of the invention. Said wax formwork elements 130

and 230 lean against a supportive plate 41, being part of a standard formwork back structure, comprising C-beams 42 against which the negative wax form elements 130 and 230 are positioned. The exact type of standard back structure can vary widely comprising different types of steel beams, wood beams, aluminium formwork systems etc. . The relationship between the scaffold parts is maintained through the usual tie rods 43 extending horizontally between the scaffold parts. This back structure defines – together with the internal wax formwork elements - a cavity 51 which is – for illustrations purposes – half-filled with concrete 50. The embodiment according to Fig. 3 does not use any steel reinforcement parts which might be positioned inside cavity 51.

10

Fig. 4 shows a cross section of Fig. 3 showing the hollow nature of the wax form elements 130 and 230 with indentations 34. These indentations are shown in a detailed partly transparent view of the wax form work element 30 in Fig. 5.

15 The wax used was Paramelt Argueso Maco Reclaim Wax. Said wax has a softening point of 66 degree Celsius and a melting point of 77 degree Celsius. The density is 950 kg/m^3 .

If the molten wax 32 is poured directly into the mould as prepared according into Fig. 1 to 2, then the surface 35 opposite to the adjustable surface 10 as well as opposite to the mould frame 20 may comprise marks from the temperature shock when the molten wax 32 is poured into the frame. This can be countered through heating the frame parts or the arrayed blocks forming the indentations 34.

It is preferred that the indentations 34 are regular since regular arrayed blocks 61 can be chosen. In order to obtain a good structural integrity, the indentations 34 have a dimension of e.g. 10 to 15 centimetres. The side walls 36 forming a grid of webs on the upper side of wax form work element 30 have preferably a dimension between 2 and 5 centimetres and more preferably between 2 and 3 centimetres. The minimum dimension of an edge, shown as reference numeral 37 in Fig. 5, should not be less than 5 to 10 centimetres. The ratio between the dimensions mentioned is a preferred feature and important to obtain a better structural integrity. Therefore the ratio between the thicknesses of the walls 36 against the size of the indentations 34, which might be irregular as mentioned above, can vary between 1 to 2 and 1 to 7, preferably between 1 to 3 and 1 to 5. The walls 36 can be slightly tapered

so that the angle between the bottom 38 of each indentation 34 and the adjacent walls 36 is between 90.5 to 92 degrees, preferably about 91 degrees.

In order to have a good structural integrity of the wax form element 30 the minimum amount of wax below the indentations 34 e.g. the distance between the bottom 38 of each indentation 34 and the lower external surface 35 should not be smaller than 3 to 5 centimetres. As can be seen in Fig. 5, the relevant material thickness 39 varies in portions with a high curvature. Beside the effect on the structural integrity of the wax form element 30 the use of indentations 34 separated by webs 36 also decrease the weight of the wax form element 30.

The external dimensions of every wax form element 30 depend on the concrete structure to be formed and the equipment used. Applicant has successfully tested dimension between 20 centimetres and 3 meter, especially formwork elements for 2D dimensions of about m². It is possible to increase the structural integrity of the wax form elements 30 through use of integrated armature reinforcements which can provide attachment points to neighbouring wax form elements.

20

LIST OF REFERENCE SIGNS

5	fabrication site	31	wax
10	adjustable initially planar surface	32	molten wax
10'	adjusted surface	34	indentation
15	transport to the installation site	35	exterior surface
16	transport from the installation site	36	side wall
20	mould frame	37	minimum edge
20'	adjusted mould frame walls	38	bottom
21	lower edge	39	material thickness
30	wax formwork element	40	support structure
		41	protective plate
		42	C-beam
		43	tie rod

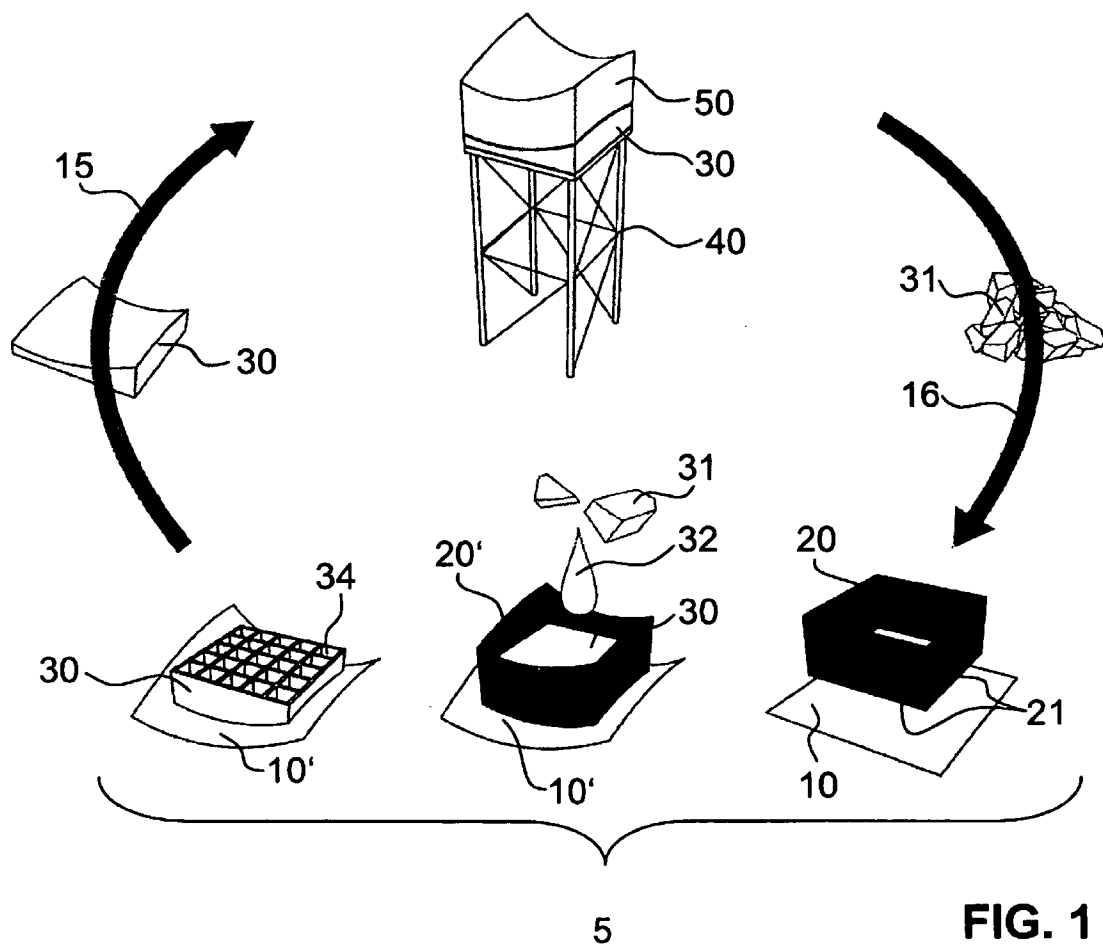
50	concrete element	63	block distance
51	cavity	130	wax formwork element
60	block array	230	wax formwork element
61	arrayed block		
62	square ground surface		

CLAIMS

1. A method for casting concrete or concrete like elements where said elements may have an amorphous shape, comprising
 - a) providing a mould, comprising a bottom surface (10') and side surfaces (20'), wherein the bottom surface (10') is an adjusted surface (10') having the curvature of the front surface of the concrete or concrete like element to be casted, and wherein side surfaces (20') comprise a number of adjusted side surfaces (20') joining the adjusted surface (10') at lines providing the edges of the front surface of the concrete or concrete like element to be casted,
 - b) pouring molten wax (32) into the mould,
 - c) solidifying the wax (32) to form a solid wax formwork element (30),
 - d) mounting the solid wax formwork element (30) on site into an outer load bearing support structure (40; 41, 42) creating a space for the concrete or concrete like element to be casted,
 - e) pouring fresh concrete or other concrete like material into the cavity,
 - f) curing the concrete or other concrete like material, and
 - g) removing the outer load bearing support structure (40; 41, 42) as well as the solid wax formwork element (30).
2. The method according to claim 1, wherein the step g) is followed by a step h) of breaking up the wax formwork elements (30) and re-melting them to form a new, especially different wax formwork elements (30).
3. The method according to claim 1 or 2, wherein the adjusted surface (10') in step a) is generated starting with an adjustable plan smooth surface (10) made of a plastic sheet, a reinforced plastic sheet or a textile structure.
4. The method according to claim 3, wherein each adjusted side surface (20') comprises a needle bed of needles being in contact with the adjusted surface (10') in a sealing manner.

5. The method according to claim 3 or 4, wherein the number of adjusted side surfaces (20') spans an extruded curve form, especially a rectangular, a polygonal form or a round or elliptical form.
6. The method according to any one of claims 1 to 5, wherein the mould of step a) is closed on the back side with an array (60) of rods (61), oriented essentially in parallel to the adjusted side surfaces (20'), wherein the rods (61) are arranged in rows and columns with gaps (62) between adjacent rods (61) or between rods (61) and the adjacent adjusted side surface (20'), wherein the front surfaces of the rods (61) are positioned at least in a distance from the adjusted surface (10') being identical or bigger than the width of said gaps (62), wherein after step c) the solid wax formwork element (30) comprises a number of indentations (34) on its back complementary to the positioning of the array (60) prior to pouring of the molten wax (32).
7. The method according to any one of claims 1 to 6, wherein after step g) the material of the solid wax formwork element (30) is reused for providing molten wax (32) within the creation of a further solid wax formwork element (30) in a following step b).
8. The method according to any one of claims 1 to 7, wherein the molten wax (32) is poured in step b) near and at the lowest part of the adjusted mould part elements (10' and 20').
9. The method according to any one of claims 1 to 8, wherein prior and/or during step b) the adjustable mould frame parts (20'), the adjustable planar surface (10') and/or the additional optional array (60) of rods (61) all or partly being equipped with heating elements are heated for heightening the temperature of the frame to a temperature in the vicinity of the fusion temperature of the wax (31) for a controlled solidification of the molten wax (32) through cooling of said elements (10', 20', 61).
10. The method according to any one of claims 1 to 8, wherein the wax (30, 32) used in step b) has a softening point higher than 60, preferably between 70 to 80 degrees centigrade.

11. Solid wax formwork element (30) comprising a front surface being complementary to the front surface of the concrete or concrete like element to be casted and having a back surface comprising indentations (34) providing an array of webs (36) providing structural integrity to the wax formwork element (30).



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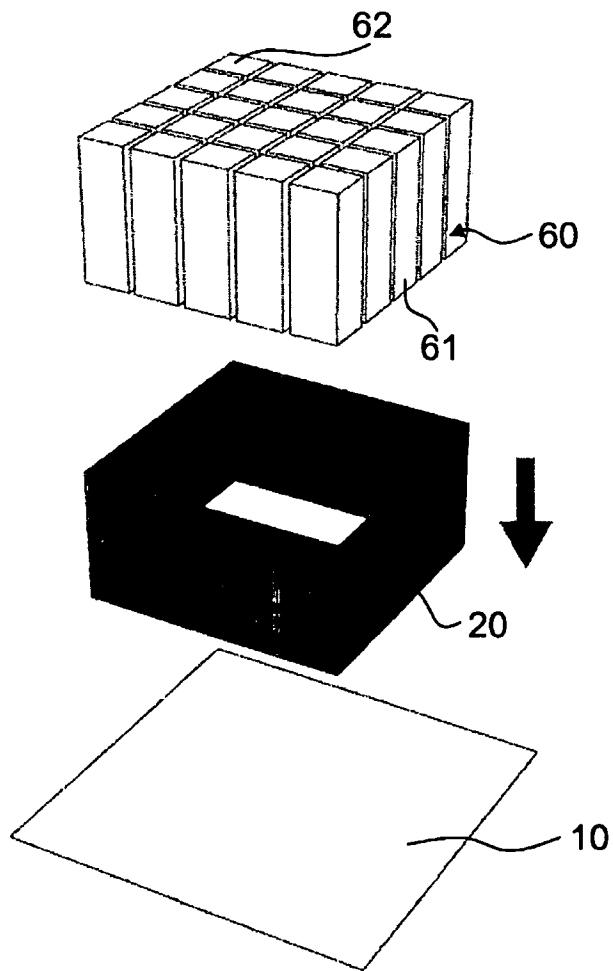


FIG. 2A

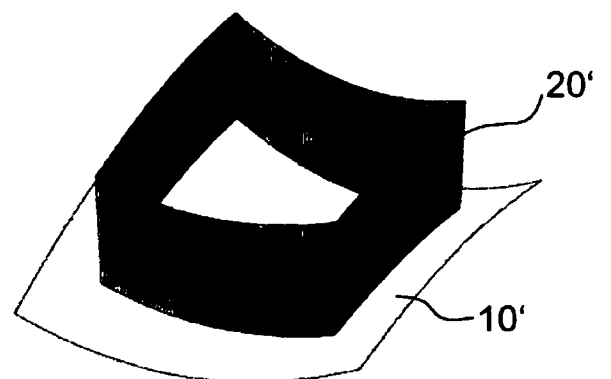
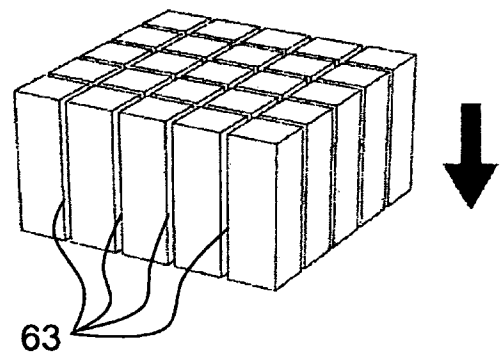


FIG. 2B

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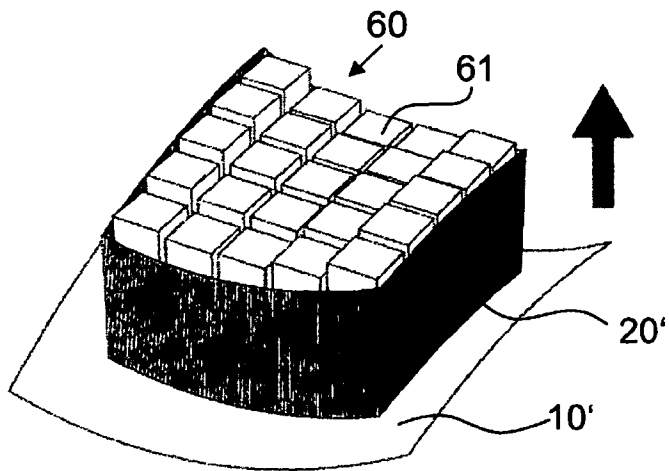


FIG. 2C

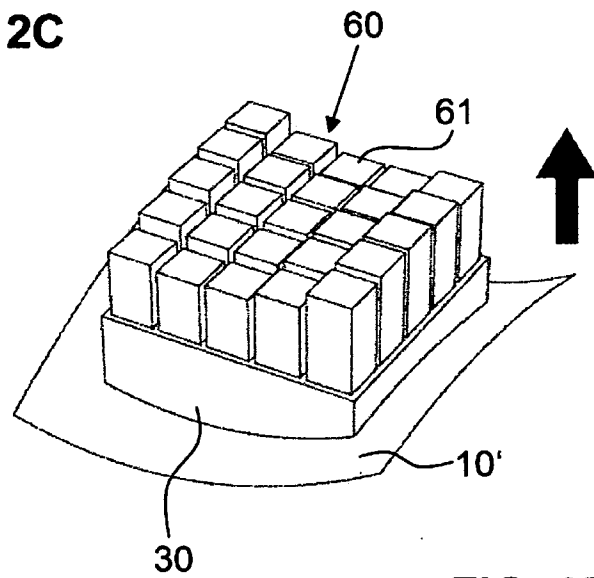


FIG. 2D

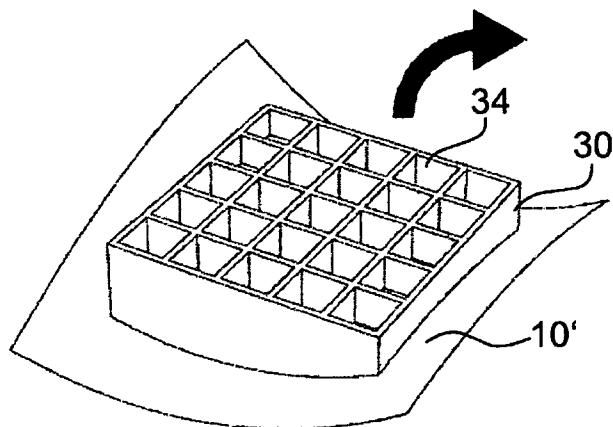


FIG. 2E

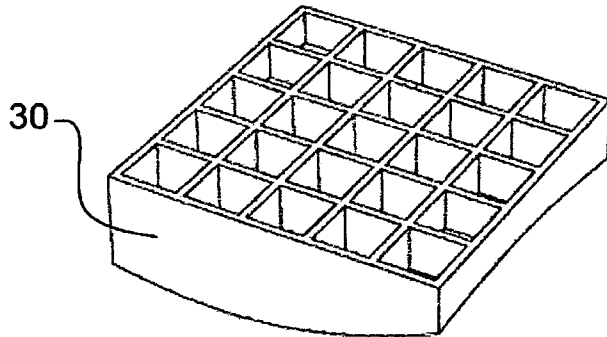


FIG. 2F

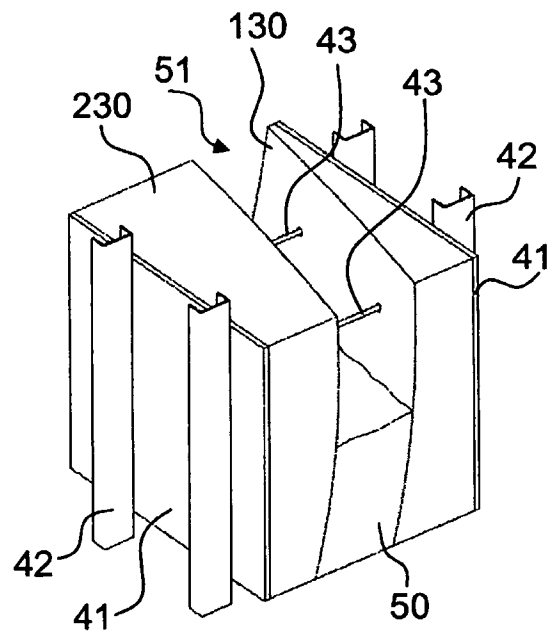


FIG. 3

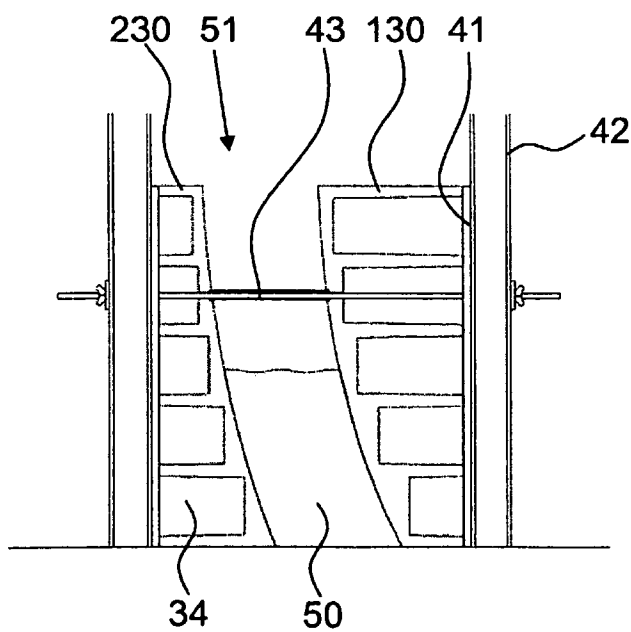


FIG. 4

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